Electrical Engineering Research Laboratory

The University of Texas

Report No. 70   30 October 1953

**Propagation of 8.6-Millimeter Radio Waves
Over a 50 Mile Path**

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PROPAGATION OF 8.6-MILLIMETER RADIO WAVES
OVER A 50 MILE PATH

by

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ABSTRACT

Propagation measurements are reported for a wavelength of 8.6 millimeters over a line-of-sight path 50 miles long. Simultaneous measurements on a wavelength of 3.2 centimeters are used for comparison with millimeter data. The median signal level for 8.6 millimeter waves was 10.4 decibels below the free space value and six decibels below the value calculated by taking into account the oxygen and water vapor absorption. The 3.2-centimeter median signal level was 1.5 decibels above the free space value.

No short time fluctuations were noted in the angle of arrival of 8.6-millimeter waves even when rather large variations in signal level were observed. Slow fluctuations in the signal level of the two frequencies correlated fairly well for fades with periods longer than 15 seconds. Rapid scintillation in the 8.6 millimeter waves sometimes greater than 16 decibels from maxima to minima did not have a counterpart in the 3.2 centimeter waves.

I. INTRODUCTION

In a previous report,[1] radio propagation measurements at a wave length of 8.6 millimeters over path lengths of 3.5, 7, and 12 miles were described. This present report is an extension of these measurements to a line-of-sight path approximately 50 miles in length.

Height-gain curves were taken over a range from 2 to 12 feet above ground. Time runs of about five minutes duration were taken at two heights and angle-of-arrival measurements were made with a two antenna interferometer. The signal level was relative to measurements made at a range of four miles. The data were taken between August 6 and August 21, 1953.

For comparison purposes, simultaneous measurements over the 50 mile path were made at a wavelength of 3.2 centimeters. Height-gain and time runs were taken simultaneous with those made at the millimeter wavelength.

II. DESCRIPTION OF PATH

The path was that established by the Central Radio Propagation Laboratory of the National Bureau of Standards for tests on other frequencies.[2]

The transmitter was located at the summit site on Cheyenne Mountain near Colorado Springs, Colorado. The receiver was on the plains east of Colorado Springs

at the location designated as Kendrick Station by CRPL. The profile as given in the Bureau of Standards Report[2] is reproduced as Figure 1.

A view along the path from the transmitter site is shown in Figure 2 and the general character of the terrain around the receiver is shown in Figures 5 and 6.

The signal level calibration was made at a site at Camp Carson, approximately 4 miles along the path from the transmitter. A view of Cheyenne Mountain from the calibration site is shown in Figure 3.

III. TRANSMITTING EQUIPMENT

The transmitting equipment was located in a small shelter house on the edge of the bluff in front of the summit house of the Central Radio Propagation Laboratory on Cheyenne Mountain as shown in Figure 4.

The signal source for the 8.6 millimeter wavelength was a klystron (Sylvania type 5789). The power output was monitored by pulse comparison on an oscilloscope. The antenna used at the transmitter was a conical horn 1.16 inches in diameter with a gain of 20 db. This horn is barely visable in Figure 4 at the edge of the shelter.

The transmitter for the 3.2-centimeter wavelength used as a signal source, a reflex klystron (Raytheon 2K 39) operating as a cw generator. A bolometer in a conventional bridge circuit was used for relative power measurements. The 30 inch parabolic reflector visible in the foreground of Figure 4 was used as the antenna to provide a gain of 33 decibels. The antennas were pointed to provide maximum signal at the receiver.

IV. RECEIVING EQUIPMENT

Two views of the receiving setup are shown in Figures 5 and 6. Figure 5 shows the 8.6 millimeter receiver at a height of six feet on the framework used for taking height-gain runs. The heavier tower in the background is that of the Bureau of Standards. Figure 6 shows the millimeter receiver on the pole with the two antenna system for angle-of-arrival measurements. The 3.2 centimeter receiver is seen in the lowest position on the height-gain elevator.

The receiver for the 8.6 millimeter signal was a conventional syperheterodyne with a reflex klystron (Raytheon QK 291) as a local oscillator. The i-f amplifier had a band pass of 20 megacycles. The pulses from the i-f amplifier were integrated and applied to a vacuum-tube voltmeter which drove an Esterline-Angus Recorder. The antenna used was the conical horn shown on the receiver in Figure 5. This horn was 32 inches long with a mouth opening of 4.75 inches. Its gain was 30 decibels. A signal generator was used to simulate the signal from the transmitter for receiver calibration.

The receiver for the 3.2 centimeter wavelength was a superheterodyne whose

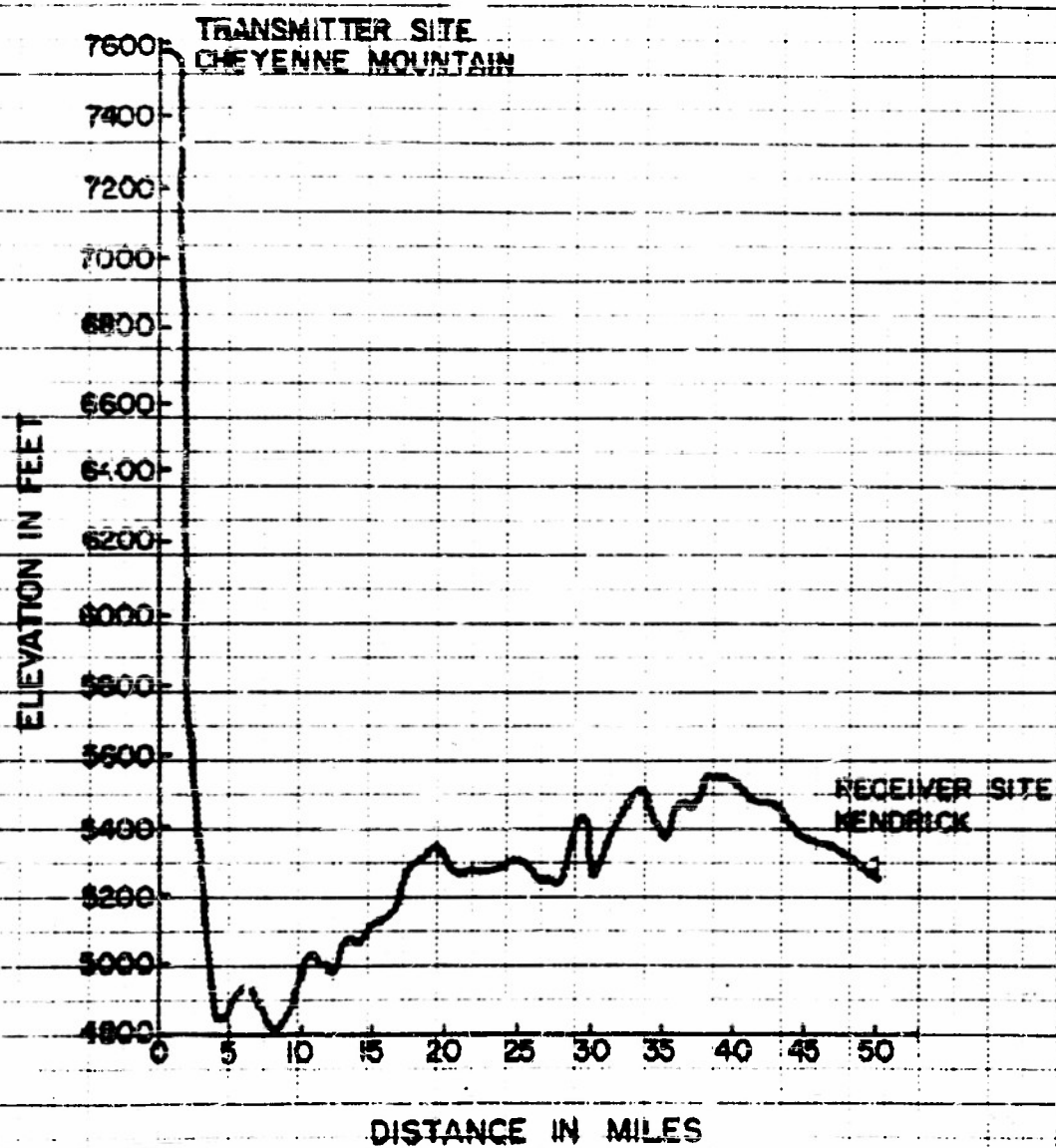FIG I

PATH PROFILE

FIG. 2
TRANSMISSION PATH FROM CHEYENNE MOUNTAIN

FIG. 3

CHEYENNE MOUNTAIN FROM CALIBRATION SITE

FIG. 4

TRANSMITTING EQUIPMENT ON CHEYENNE MOUNTAIN

FIG. 5

RECEIVER SET UP SHOWING mm EQUIPMENT OF HEIGHT-GAIN TOWER

FIG. 6

RECEIVER SET UP SHOWING mm ANGLE-OF-ARRIVAL EQUIPMENT AND CM
RECEIVER ON HEIGHT-GAIN TOWER

local oscillator was frequency modulated at a rate of 120 cycles per second over a frequency range of 15 megacycles per second. The mean frequency of the local oscillator was adjusted to heterodyne with the signal from the transmitter at the mid-frequency of the i-f amplifier in the receiver. The resulting pulses were demodulated, integrated and applied to a vacuum tube voltmeter which drove an Esterline-Angus recorder. The antenna used at the receiver was an 18 inch parabolic reflector with a gain of 30 db. A signal generator was used to simulate the transmitted signal for receiver calibration.

V. CALIBRATION TESTS

An arrangement of equipment similar to that used at the receiving site was made at a calibration site at Camp Carson, four miles from the transmitter along the transmission path.

Height-gain curves at the calibration site established that the reflected component was eliminated by the narrow beam widths of the antennas and the elevation of the terminals above the intermediate ground. The signal level established at the four-mile distance was used as reference for the 50-mile data. The time variation of the 8.6 millimeter and 3.2 centimeter signals were 0.7 and 0.2 decibels respectively.

The 8.6 mm reference levels had shifted 2 decibels relative to each other between calibrations made just prior to and immediately after the test period and the average of the two reference values was taken for comparison with the long path data. The references for 3.2 cm signal had not shifted appreciably between the two calibrations.

VI. HEIGHT-GAIN CURVES AT 50 MILES

An example of the measured height-gain curves for the 8.6 millimeter wavelength and an example for the 3.2 centimeter wavelength are shown in Figure 7. Since time variations tended to obscure space variations, the sample was selected for a time when the fluctuations at a fixed height were small.

The calculated interference patterns for specular reflection with a coefficient of reflection of 0.2 and 0.4 for the 8.6 mm and 3.2 cm respectively are shown by the dashed lines in Figure 7.

The time variations of the 8.6 millimeter signal were much larger than the space variations; therefore, space variations were generally obscured on the height gain runs. The median value of 132 runs showed a signal level almost independent of height with the variations primarily due to space variations.

Since the time variations of the 3.2 centimeter signal were small relative to the space variations, the general character of the height-gain curves were repeated from run to run, and a median value of 84 height-gain runs showed the lobe structure due to space variations. These average height-gain curves are shown in Figure 8. Thus it is seen that no long time signal advantage is gained at 8.6 millimeters by a particular height choice.
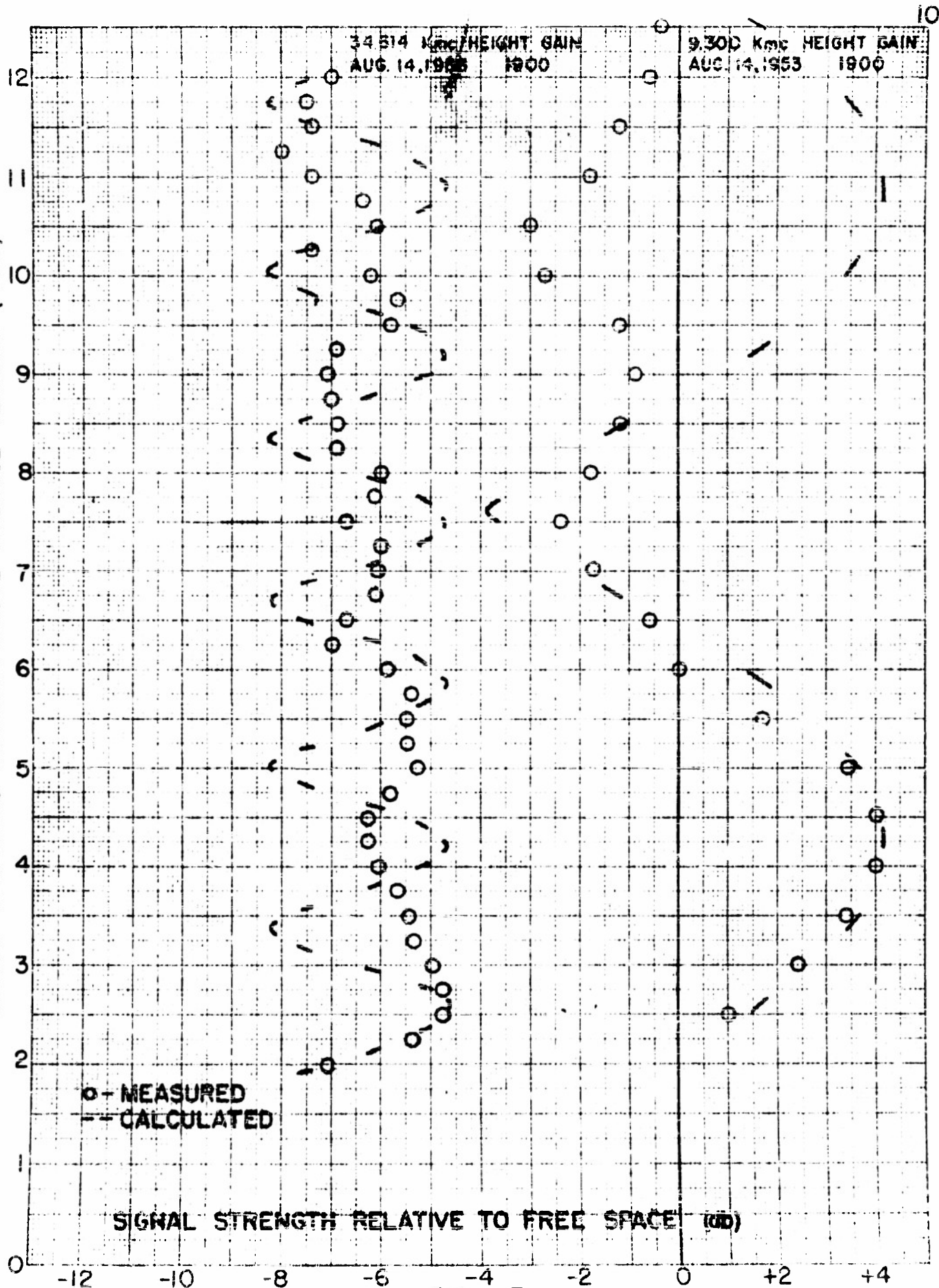
FIG. 7
TYPICAL HEIGHT-GAIN CURVES
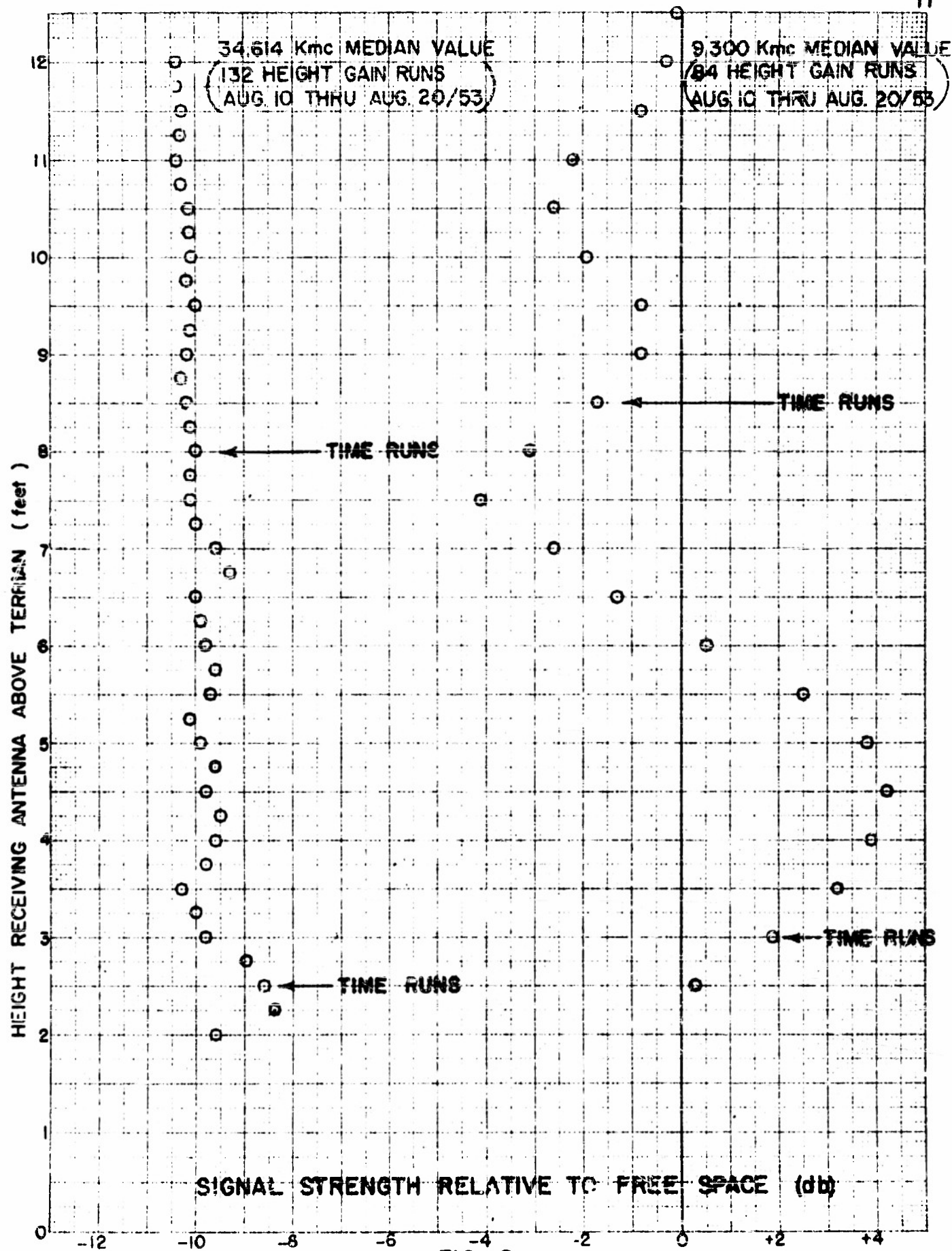
FIG. 8
MEDIAN VALUE HEIGHT-GAIN CURVES

The interference pattern for the upper part of the 8.6 millimeter height-gain curve was very small. Hence, the direct wave signal level was established as the average of the upper 6 feet of the height-gain curve. The mean signal level for the time runs with the receiver at fixed heights were corrected by an amount the height-gain curve indicated the signal level at those heights to differ from the direct wave signal level.

The interference pattern of the 3.2 centimeter height-gain curve was of appreciable magnitude. The direct wave signal level was determined by assuming the first maximum and minimum were produced by two wave components, a direct and a reflected wave. The signal levels of the time runs were corrected by an amount the height-gain curve indicated the signal at the measuring height differed from the direct wave signal level. The lower coefficient of reflection that might be expected from an average of many height-gain runs might be in some degree responsible for the median value of the 3.2 centimeter signal level being as high as it is above the free space value.

VII. MEDIAN SIGNAL LEVELS

The median signal levels were determined for all of the five-minute-time runs and are shown in Figure 9 for two receiver heights. The median direct signal level for 3.2-centimeter wavelengths and for 0.86-centimeter wavelengths are shown with open and solid circles, respectively. The vertical lines through the points indicate the range of fluctuations.

For each measurement period, wet and dry bulb temperature readings were taken at the two terminals of the path. The moisture content of the air was determined for each set of readings and the values thus determined are shown in Figure 10.

In order to calculate the loss due to water vapor, the moisture contents at the two ends of the path were averaged. It is realized that this average may not be truly representative of the conditions along the path, but no better approximation was known. The losses due to water vapor and oxygen absorption were calculated by the formulas given by Van Vleck in reference[5] and are shown as the dashes in Figure 9.

The median of all of the runs for the 8.6-millimeter wavelength was measured to be 10.4 decibels below the free space value while the median loss due to water vapor and oxygen absorption was calculated to be 4.4 decibels. An unaccounted loss of 6 decibel is therefore present.

The median of the 3.2-cm wavelength signal levels was 1.5 decibels above the free space value and the water vapor and oxygen should have negligible loss at this frequency.

The two wavelengths followed the same general trend over the measurement period and this same trend although smaller in amplitude was followed by the signal level calculated from the moisture content of the air. The changes in the 3.2-centimeter wavelength are obviously not due to changes in water vapor absorption. Some sort of focusing and defocusing of the energy may be involved in the signal level changes.

FIG. 9

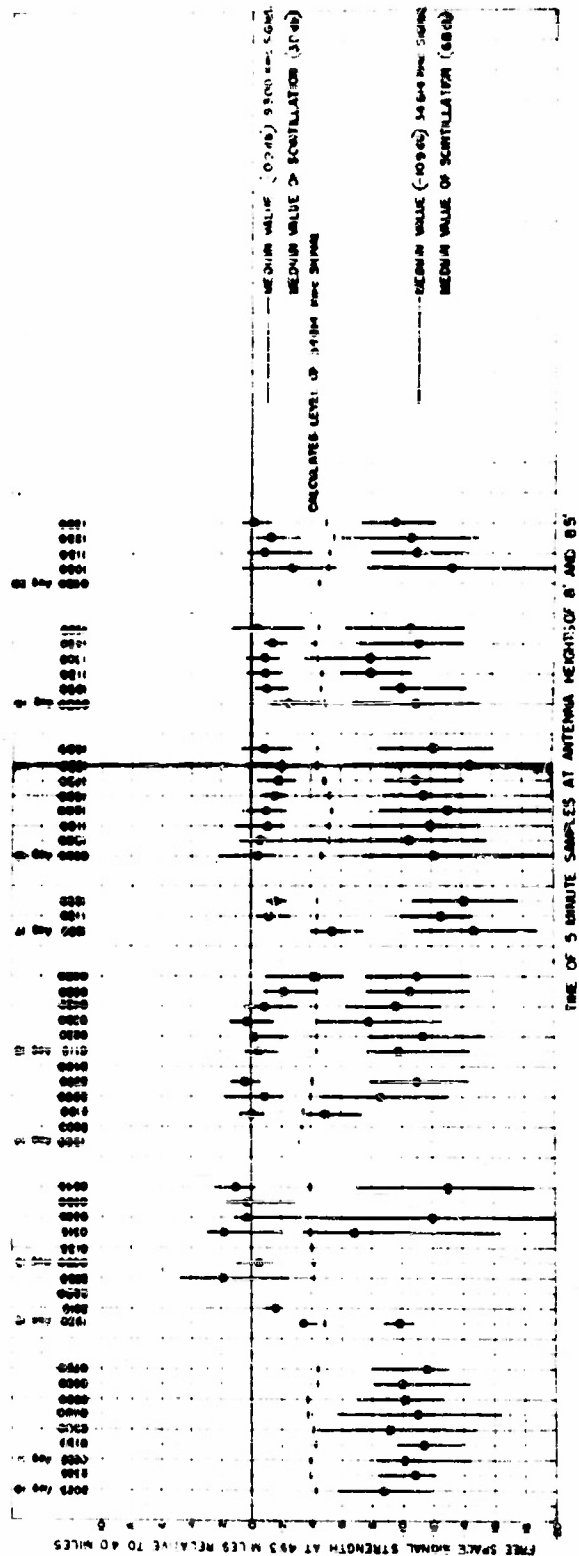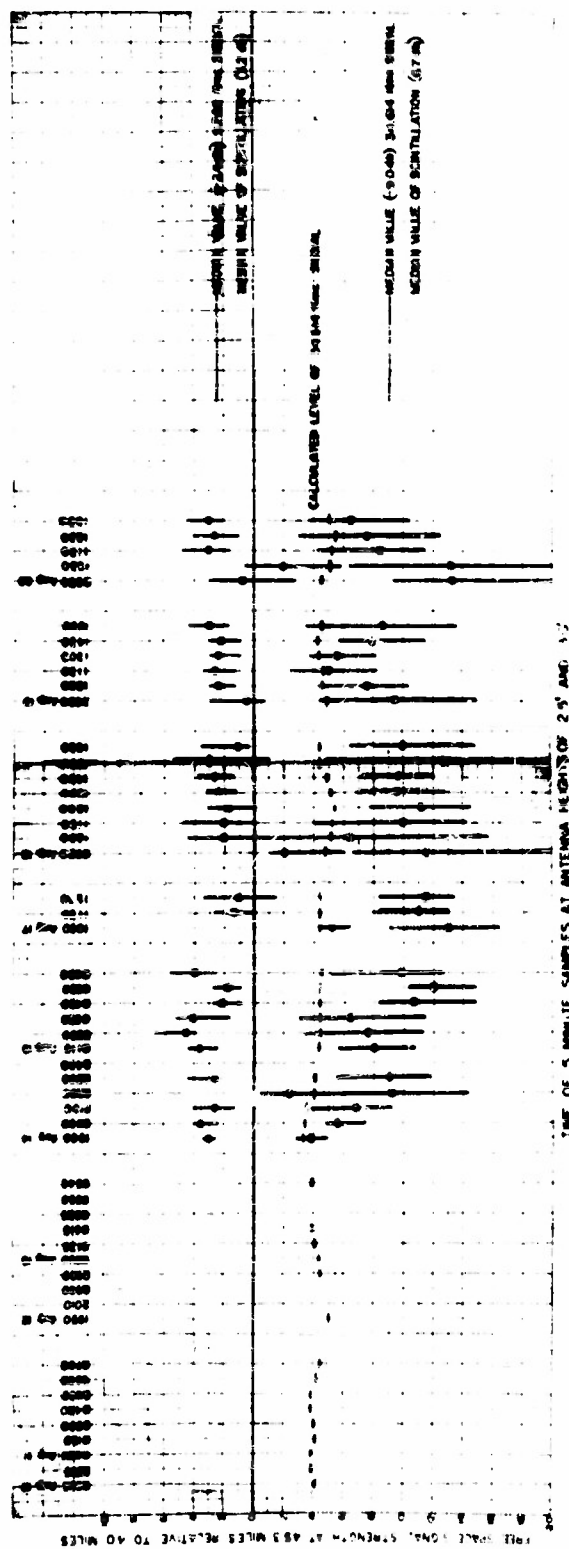SIGNAL LEVEL AND FLUCTUATION DATA

× KENDRICK
● CHEYENNE MOUNTAIN

WATER VAPOR GRAM/METER³

16 14 12 10 8 6 4 2

AUG. 10 AUG. 11 AUG. 12 AUG. 14 AUG. 15 AUG. 17 AUG. 18 AUG. 19 AUG. 20
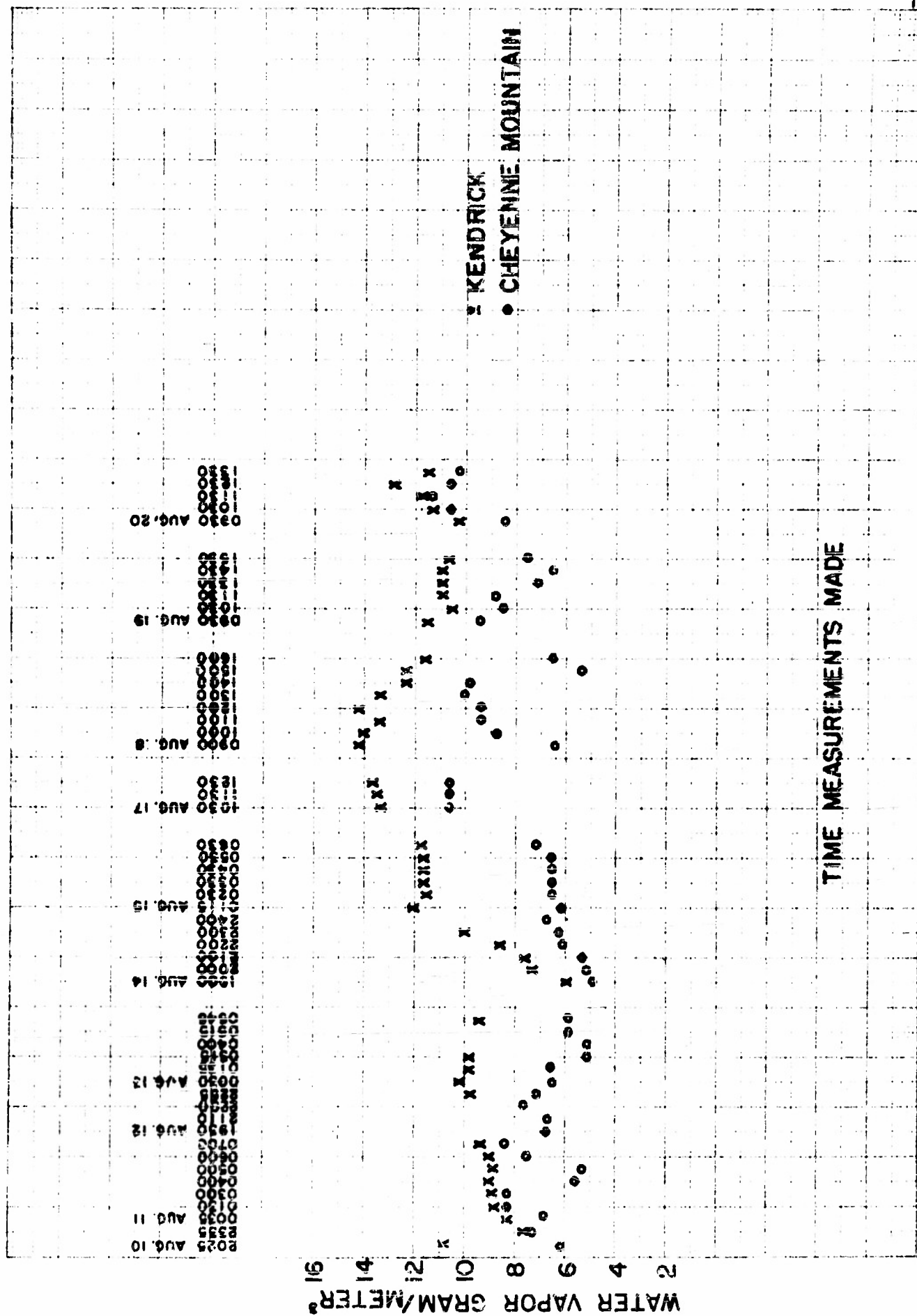
TIME MEASUREMENTS MADE

FIG. 10

MOISTURE CONTENT OF ATMOSPHERE

VIII. SIGNAL FLUCTUATIONS

The range of fluctuations for each measurement period have been shown in Figure 9. Samples of the original data are shown in Figure 11 which contain examples ranging from very little scintillations in the upper left diagram to large scintillations in the lower right diagram.

Correlation of the fluctuations at 0.86-centimeter wavelengths and 3.2-centimeter wavelengths were good for periods greater than approximately 12 seconds. The 0.86-centimeter wavelengths had signal strength fluctuations of the order of 16 db whose periods were less than 5 seconds. Signal strength fluctuations at these higher frequencies were absent from the 3.2-centimeter wavelength.

The frequency distribution of the fluctuations is shown in Figure 12 for a five minute sample taken at 1000 on August 18, 1953 (See Figure 11). This sample was selected as one which had large amplitude scintillations of the 8.6 millimeter wavelength. This figure shows the general agreement between the power spectrum graphs for the longer-period fluctuations and the sharp discrepancy between the two curves for shorter-period fades. As previously noted, the 3.2-centimeter recordings contained little indication of fluctuations with periods less than 12 seconds, but the 8.6 millimeter component had a considerable amount of the short period fading.

A second sample taken at 1545 on August 19th (See Figure 11) was chosen as a case when the short period fluctuations were considerably reduced. The power spectrum of the fluctuations for this sample shown in Figure 13 confirm this reduction at the high-frequency end of the graph, with the general agreement at the low-frequency end still apparent.

The cross-correlation coefficient between the fluctuations of the two frequencies was found to be 0.77 for the sample for which there was little high-frequency fading of the 8.6 millimeter waves, but was found to be only 0.33 for the sample for which the high-frequency fading was present to obscure the correlation of the low-frequency fading.

In order to compare the magnitudes of the signal fluctuations on the 50 mile path with those found on the shorter paths described in Report No. 69, the shorter path data are included with the 50-mile one in Table I which gives the maximum, minimum and median fluctuation ranges.

Table I

Fluctuation Ranges

Wave Length	Path Length	Fluctuation Range db		
cm	Miles	Maximum	Minimum	Median
0.86	3.5	1.8	0.4	0.8
0.86	7.2	4.6	0.2(Fog)	1.0
0.86	12.1	5.0	0.8	2.4
0.86	49.3	164	2.0	6.8
3.2	49.3	8.0	1.0	3.1

From this table, it is evident that the millimeter fluctuation range increase is approximately proportional to distance.
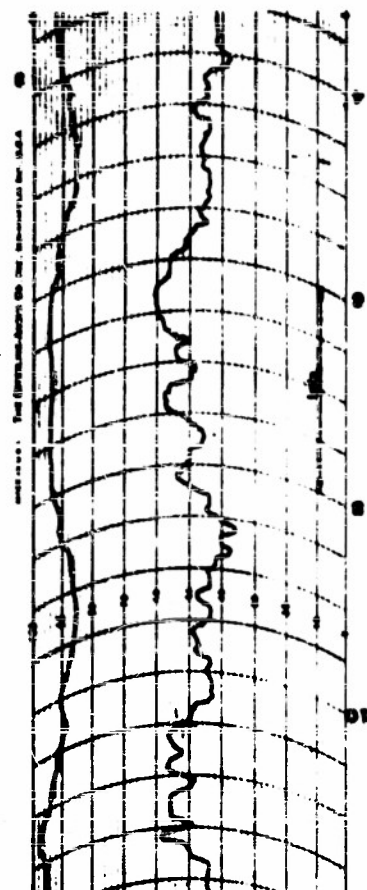
ANTENNA HEIGHT 2.5'
AUGUST 14/53 2100

ANTENNA HEIGHT 2.5'
AUGUST 19/53 2000
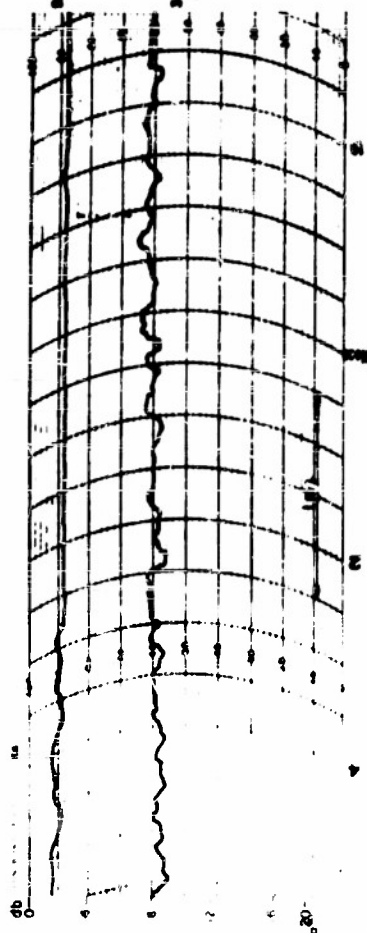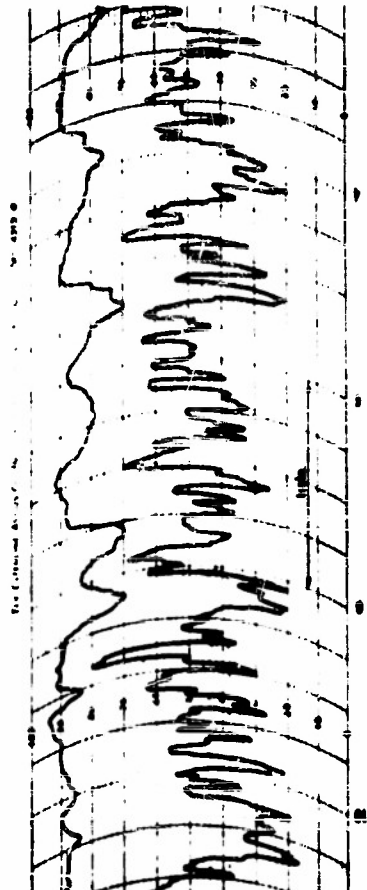
ANTENNA HEIGHT 2.5'
AUGUST 14/53 1905
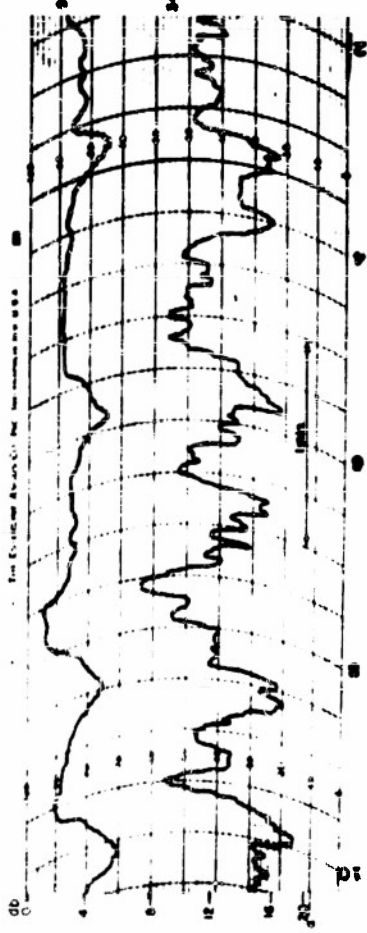
ANTENNA HEIGHT 2.5'
AUGUST 19/53 1545

FIG. 11

SAMPLE OF ORIGINAL DATA SHOWING SIGNAL
FLUCTUATION
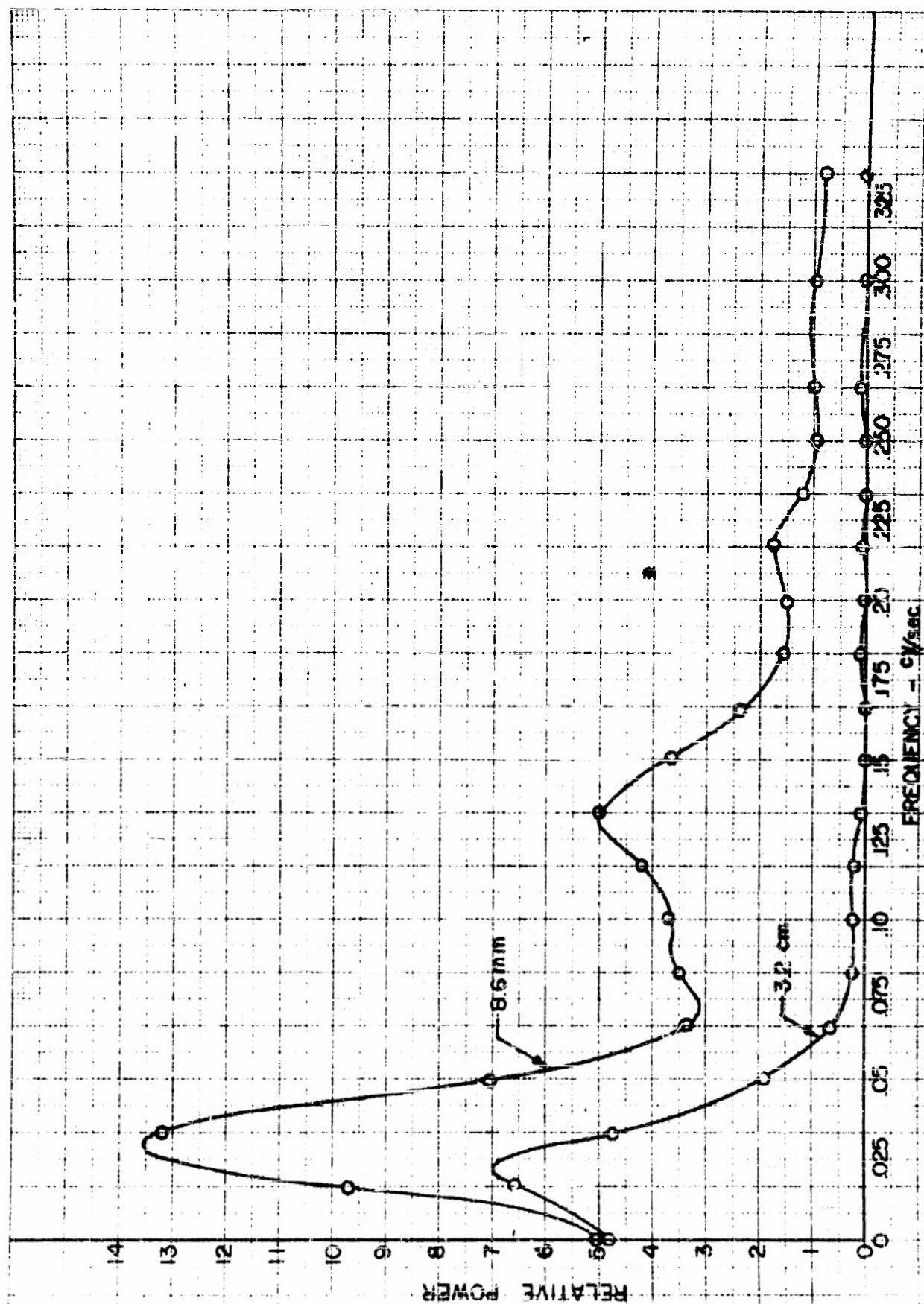
POWER SPECTRUM OF SIGNAL FLUCTUATIONS FOR LARGE MAGNITUDE SHORT PERIOD FADES

FIG. 12

17

POWER SPECTRUM OF SIGNAL FLUCTUATIONS FOR SMALL MAGNITUDE SHORT PERIOD FADES

FIG. 13

IX.   ANGLE-OF-ARRIVAL MEASUREMENTS

On the 50-mile path, a simple interferometer at 0.86-millimeter wavelength was set up as shown in Figure 6. It was possible to turn this system either horizontally or vertically and in either position, the signal could be cancelled out. Turning the interferometer through an angle of one mil from the null ca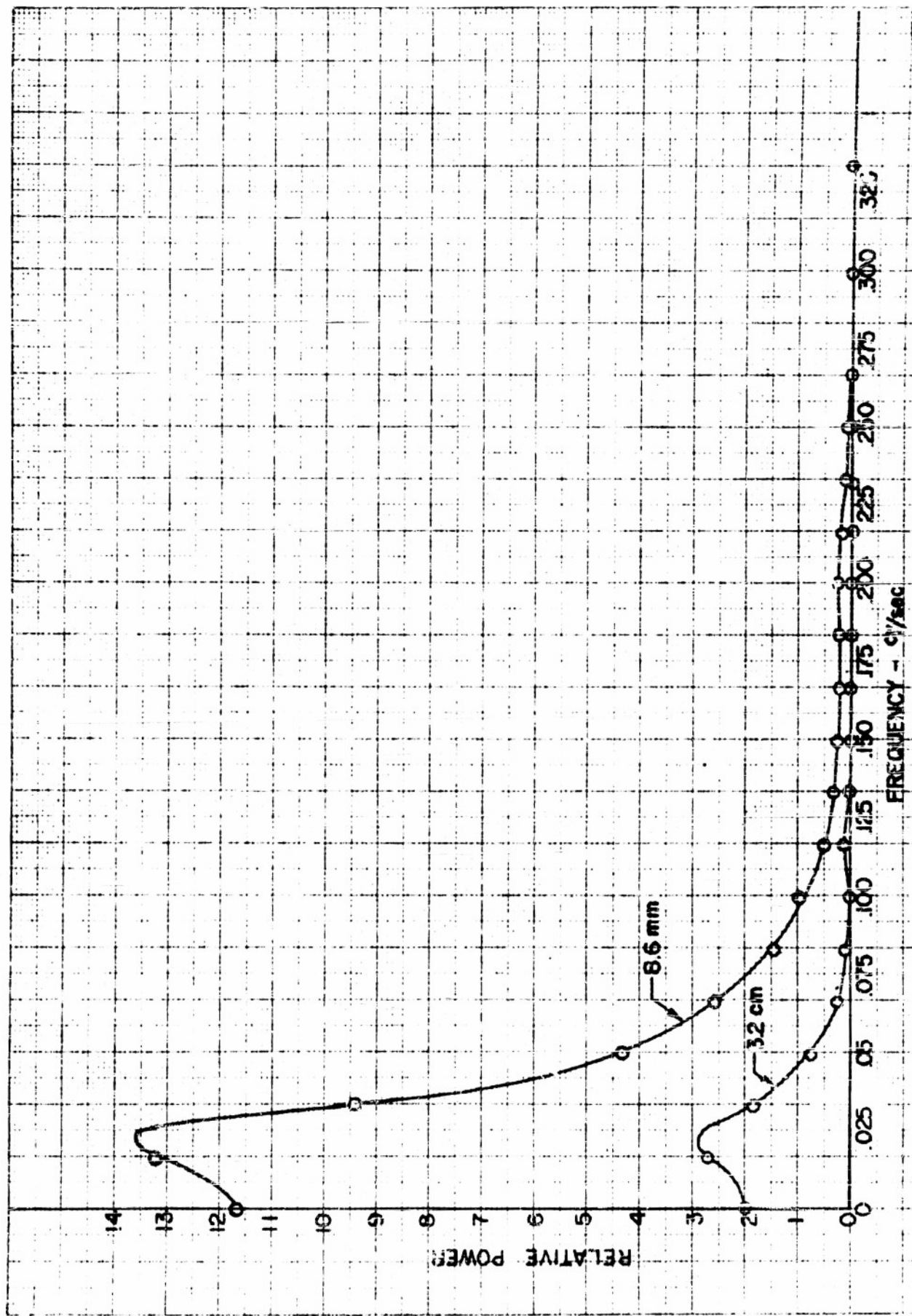used a fairly strong signal to appear. The signals received with the interferometer on a null and with it shifted off the null by one mil are shown in Figure 14 for both horizontal and vertical orientation.

No measurable shift in the position of the nulls occurred during the five minute sampling periods even on days when large fluctuations in signal level were observable.

A change in vertical angle of arrival of about one mil was noted between day and night conditions. The daytime value was approximately 8.5 mils above the horizontal and the nightime condition was about 9.5 mils. The angle-of-arrival of a light beam at night was approximately 8.5 mils.

X.   EFFECT OF SHOWERS ALONG PATH

On several occasions, showers appeared to be falling between the transmitter and receiver. On such occasions, the signal level suffered severe attenuation and was usually reduced to the noise level. Since no data were available on the extent or nature of the showers, no quantitative study was made of the effect of the showers on the signal level.

Two examples of the magnitude of the attenuation due to rain on a three-mile path are described in Report No. 69.

XI.   WEATHER SUMMARY, 10-21 AUGUST 1953

The weather conditions occurring in the central Colorado area just east of the Rockies for the period under consideration can be divided into four relatively distinct patterns. Prior to about 1600 local time on 10 August, and following a warm front passage early on the 9th, a south to southwesterly circulation was bringing in warm and relatively humid air with midnight temperatures and dewpoints averaging about 70°F and 51°F respectively. Maximum temperatures were up to about 95°F. A well marked cold front passage at about 1600 on the 10th produced northwesterly winds and a continental polar airmass over the area. The continental polar high pressure area was centered over Colorado by late on the 11th. While the winds were back to south by this time, the period as a whole was characterized

FIG. 14

TYPICAL ANGLE -OF- ARRIVAL RECORDINGS

by a 10-12°F drop in temperature, general rains during a 24 hour period following the front passage and little change in air moisture content.

During the period August 12-14 the high pressure system weakened, moved eastward and gave a weak and confused pressure pattern over the area. A second cold front was moving very slowly southward from northwest Canada but this had little or no effect on the weather for the area under consideration. In general the winds were light and variable from the south and southeast, temperatures were gradually rising with maximum values in the low 90's and the dewpoints were the lowest of the entire observation period-averaging about 45°F although there was considerable variation from this value.

By August 15, the cold front had lined up along the Rockies and had become essentially stationary. While the area east of the divide was generally in the cool air behind the front, there were a number of small oscillations of the front back and forth across the area. Rain in the form of showers and thunderstorms was common throughout most of the rest of the observation period although it was gradually drying out by the 19th and 20th. Temperatures were among the coolest observed with maximum values in the low 80's and midnight temperature about 60°F. Dewpoints in general were among the highest observed with values ranging from 50- to over 55°F. The winds were variable, generally from the east and southeast following the anticyclonic circulation around the large high pressure system centered to the northeast of the observation area in the Minnesota-Wisconsin area.

XII. SUMMARY OF MEDIAN SIGNAL LEVELS

The median signal level measured on the paths described in Report No. 69 are compared in Table II to the signal level measured on the 50 mile path.

Table II

Summary of Median Signal Levels

Path length in miles	3.5	7.2	12.1	49.3	49.3
Wave length in centimeters	0.86	0.86	0.86	0.86	3.2
Number of samples	6	19	11	76	71
Median signal level relative to free space in db					
Measured	-1.0	-1.7	-2.5	-10.4	+1.5
Calculated	-0.5	-0.8	-1.6	-4.4	0.0
Unexplained loss in db per mile	0.14	0.13	0.07	0.12	-.03

From Table II, it is evident that the unexplained loss per mile is approximately the same for all of the 8.6 millimeter paths.

XIII. ACKNOWLEDGMENT

The cooperation of the Central Radio Propagation Laboratory of the National Bureau of Standards in permitting us to use their site and facilities in conducting these tests is gratefully acknowledged. In particular, we wish to express our sincere appreciation to Mr. K. A. Norton for his cooperation and helpful suggestions and Mr. K. O. Hornberg and the staff of local personnel at Colorado Springs for their assistance in details of the tests.

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